Space Solar Power (SSP) Concept and Technology Maturation (SCTM) Program

Systems Integration, Analysis and Modeling Breakout Session

Presented by

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Cleveland, Ohio

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Overarching Issues for Systems and Technology Breakout Sessions

What have we learned to date?

- All current SSP microwave concepts are too heavy and too costly - even invoking advanced technologies projected 20 years forward.
- Biggest drivers of electricity cost ($ per kWhr) are propulsion, PMAD, SPG, structure and ground systems (rectenna, energy storage, etc.)
- While not a major cost driver by itself, WPT sets the requirements that drive the mass and cost of the other system components and technologies.

Three things we can do about it:

- Produce new and innovative SSP system concepts that overcome the limitations of those currently proposed, e.g., HotDot Array
- Consider alternate system concepts that make use of radically different technologies, e.g., laser systems based on laser diodes or solar pumped lasers.
- Pursue technology advancements that could substantially improve the performance of existing SSP system concepts - specifically breakthroughs in
  - Efficiency
  - Mass Reduction
  - Cost Reduction
  - Increased Lifetime
  - Required Operating Environments (temperature, radiation, etc.)

Current Areas of Strong Interest and Emphasis

- **New Concept Development**
  - HotDot Array Microwave Concept (Mankins)
  - Solar-Pumped Laser Concepts (?)
- **Concept Modeling**
  - All Laser Concepts and New Microwave Concepts
  - Laser Technology Data
  - Thermal Subsystems Technology and Models
  - ACS Modeling
  - Cost Estimation and Modeling
  - Conversion to TITAN
  - Model Review and Validation
- **Concept Evaluation**
  - System Analysis and Comparsion of New Concepts
  - Technology Trade Studies

CURRENT SYSTEM INTEGRATION ACTIVITIES FOR SCTM AND TITAN

SCTM Systems Integration, Analysis and Modeling
Summary of Ongoing System Integration Activities

- **Activities and Accomplishments**
  - Proposed new SSM architecture which has since become basis for more comprehensive TITAN Model architecture
  - Restructuring SSM for inclusion in TITAN
  - Updating SSM subsystem worksheets: Thermal, Structures, SPG, PMAD, WPT, Attitude Control
  - Modeling Aerospace and Boeing Laser SSP concepts for SSM/TITAN
  - Supporting TFD concept development and modeling efforts
  - Participation in SCTM working group telecons
  - Evaluation of new SSP concepts and configurations (e.g. HotDot Array)
- **Issues**
  - Response to NRC requires higher fidelity modeling & peer review
  - Industry participation in SIWG limited by SCTM program delays
  - Need data to support laser system modeling
  - Approach to cost estimation (data and models to be used) still unclear

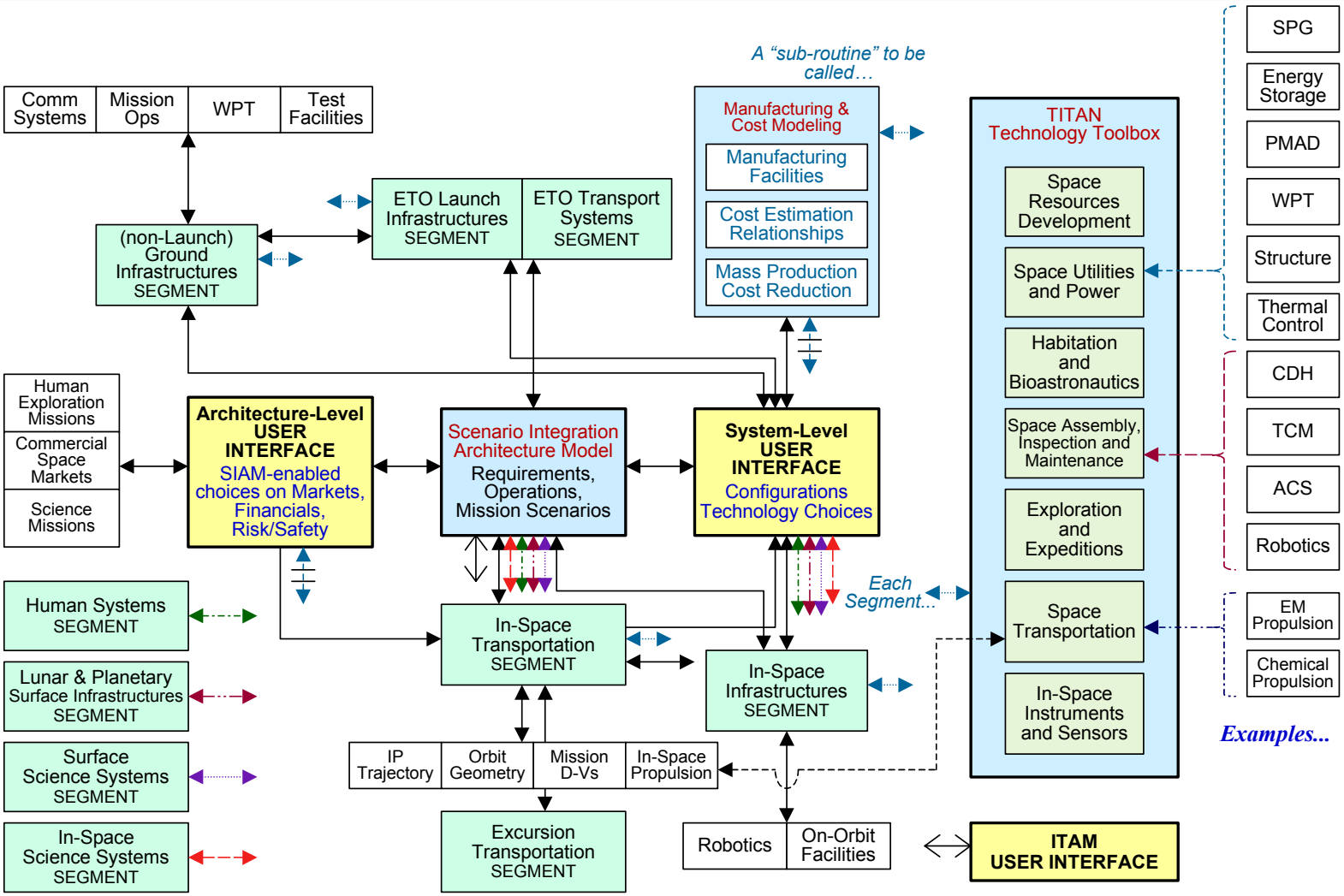
TITAN MODEL

TITAN Model Architecture

Model Description

- TITAN (THREADS Integrated Technology ANalysis) is a Microsoft Excel-based model, currently under development, that will use a modular, multi-workbook environment to quantitatively evaluate how technology choices and/or investment decisions impact the broad spectrum of HEDS systems, missions and architectures, in terms of performance, cost and risk.
- To provide a consistent basis of existing and projected technology information for use in these evaluations, TITAN will employ a technology "toolbox" based on the THREADS technology database, and by design, the user will be able to select and apply technology performance data from the toolbox, across the full range of modeled systems and missions.
- In essence, the TITAN modeling approach is designed to allow the user to "build" a mission architecture by selecting a complete set of modeled system elements from various architecture segments such as ETO Transportation Systems, Space Transportation, In-Space Infrastructure, In-Space Science, Surface Science, etc.; developing an integrated mission scenario/timeline; and selecting the system technologies to be examined, from the technology toolbox.
- Although TITAN will be specifically designed to accommodate HEDS applications, it is expected that the model will be capable of performing similar evaluations for various Earth and space science missions as well as missions for commercial space markets.

THREADS Integrated Technology ANalysis (TITAN) ModelArchitecture Overview



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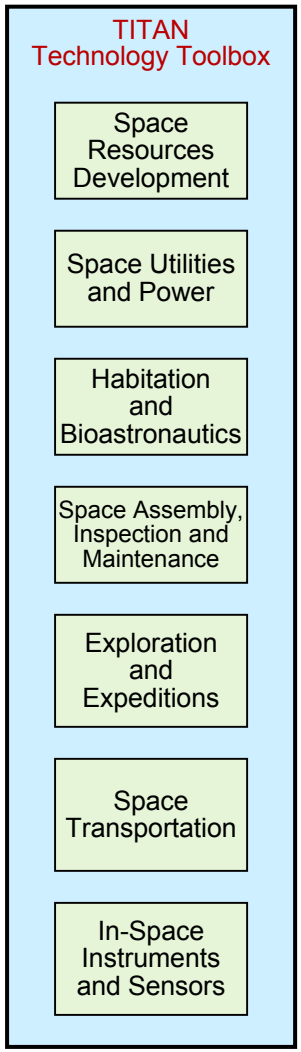
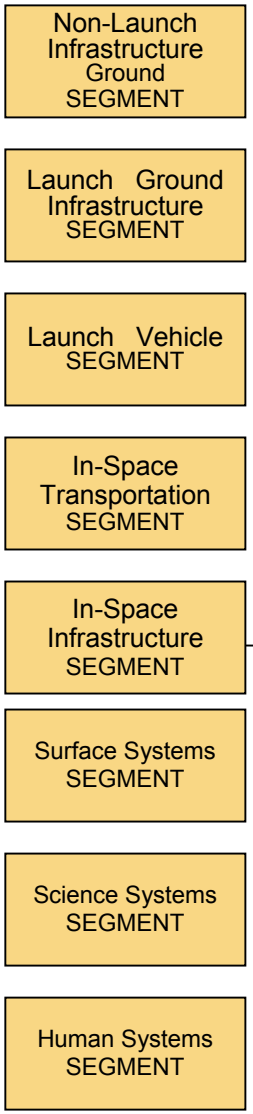
Functional Descriptions
The "TITAN Technology Tool Box" (T3B)



- **The TITAN "Technology Tool Box" (T3B) will be the primary repository for information concerning the wide array of potential technologies that might be applied in future systems -- including quantitative metrics with which options for incorporation can be assessed**
- **The T3B will provide a common "look-up table" of information concerning various technologies**
- **The T3B provides information on many different technologies…**
  - Assuring that within an analysis that the same level of technology advancement is used (or if different levels are used, that these are deliberate choices…
- **And in several timeframes, including State of the Art; Immediate Future; Mid-Term; Far-term; and Very Far-term**
- **The T3B supports Technical / Performance modeling; Cost / Economic modeling; and, Technology Assessment**
- **T3B will be organized according to the Work Breakdown Structure (WBS) of the THREADS ("Technology for Human/Robotic Exploration and Development of Space") taxonomy**

Functional Descriptions
TITAN In-Space Infrastructure Segment (ISIS)



- **The TITAN In-Space Infrastructure Segment (ISIS) will enable modeling at a strategic level of the choices of space-based infrastructure associated with the broad spectrum of HEDS mission architectures and scenarios.**
- **ISIS will rely on the T3B for information concerning the wide array of potential technologies that might be applied in future systems -- including quantitative metrics with which options for incorporation can be assessed.**
- **ISIS will possess the flexibility to model an unlimited number of different functional systems or subsegments, representing various infrastructure elements such as SSP, Fuel Depots, Gateway, Assembly Nodes, ISS, Communication Satellites, etc.**
- **ISIS will also be able to accommodate different user-defined configurations for each system/subsegment.**
- **ISIS will interface directly with SIAM to pass information to and from the System-Level User Interface (SUI), the Architecture-Level User Interface (AUI) and the other TITAN segments.**
- **ISIS will rely on SUI to specify system performance requirements, configuration, and technology choices for each subsegment; and on the AUI for mission scenario/architecture information, i.e., subsegments to be used and their number, orbits, timing, data needed from related segments, etc.**
- **ISIS will be able to provide outputs such as mass breakdowns, development costs, and parameter data for sensitivity studies directly to the user or to the user interfaces via SIAM.**

Near-Term TITAN Modeling Requirements

- **Near-Term Modeling Objective**
  - "Have something that does something by Fall." (JCM)
  - "Something" = TITAN, Alpha Version
  - "Fall" = Before December 21, 2002
- **Alpha Version Requirements (Strawman)**
  - Based exclusively on linked Microsoft Excel workbooks, with possible exception of external Cost Model which is TBD.
  - At least partial implementation/functionality of each TITAN element class, I.e., Segment, SIAM, Technology Toolbox, User I/F, Cost Model (?)
  - Contains sufficient number of Segments to model and partially analyze at least one HEDS mission architecture.
  - Demonstrates user interface, input, output and control approach.
  - Demonstrates the capability and impact of varying selected system technologies on a global or local basis.
  - Demonstrates methodology for integrating workbooks via SIAM and exchanging information between TITAN elements via ICD worksheets.
  - Other?

TITAN Model Architecture

Mission/System Candidates for Alpha Release

- **Earth Neighborhood**
  - ETO
  - Gen 4 ETO
  - Gateway
  - Large telescope
  - In-space Transportation
  - Hybrid Propulsion Module (HPM)
- **Commercial Development of Space**
  - ⇨ Space Solar Power (SSP)
  - Space Business Park (SBP), Gateway-derived
- **Science**
  - Mars Sample Return (Space Science) - only if similar to T/S choices
  - Outer Planets NEP (Space Science)
  - Earth Science Altimetry
- **Human Exploration**
  - NEP to Mars (Mars Transfer Vehicle)
  - Other specific systems (i.e. rovers, surface science, etc.) for various segments

Recommended:

- **SSP ✓**
- **Any Others?**

Major Elements of TITAN Model

- ✓ **Scenario Integration Architecture Model (SIAM)**
- • **User Interfaces (may be part of SIAM)**
  - ✓ Architecture-Level
  - ✓ System-Level
  - – ITAM
- ✓ **Technology Toolbox**
- ✓ **Life-Cycle Cost Model**
- • **Segments**
  - ✓ Ground Infrastructure
  - ✓ ETO Launch Infrastructure
  - ✓ ETO Transport Systems
  - ✓ In-Space Infrastructure
  - – In-Space Science Systems
  - ✓ In-Space Transportation
  - – Excursion Transportation
  - – Lunar & Planetary Surface Infrastructure
  - – Surface Science Systems
  - – Human Systems

✓ = Partially Implemented in Alpha Release

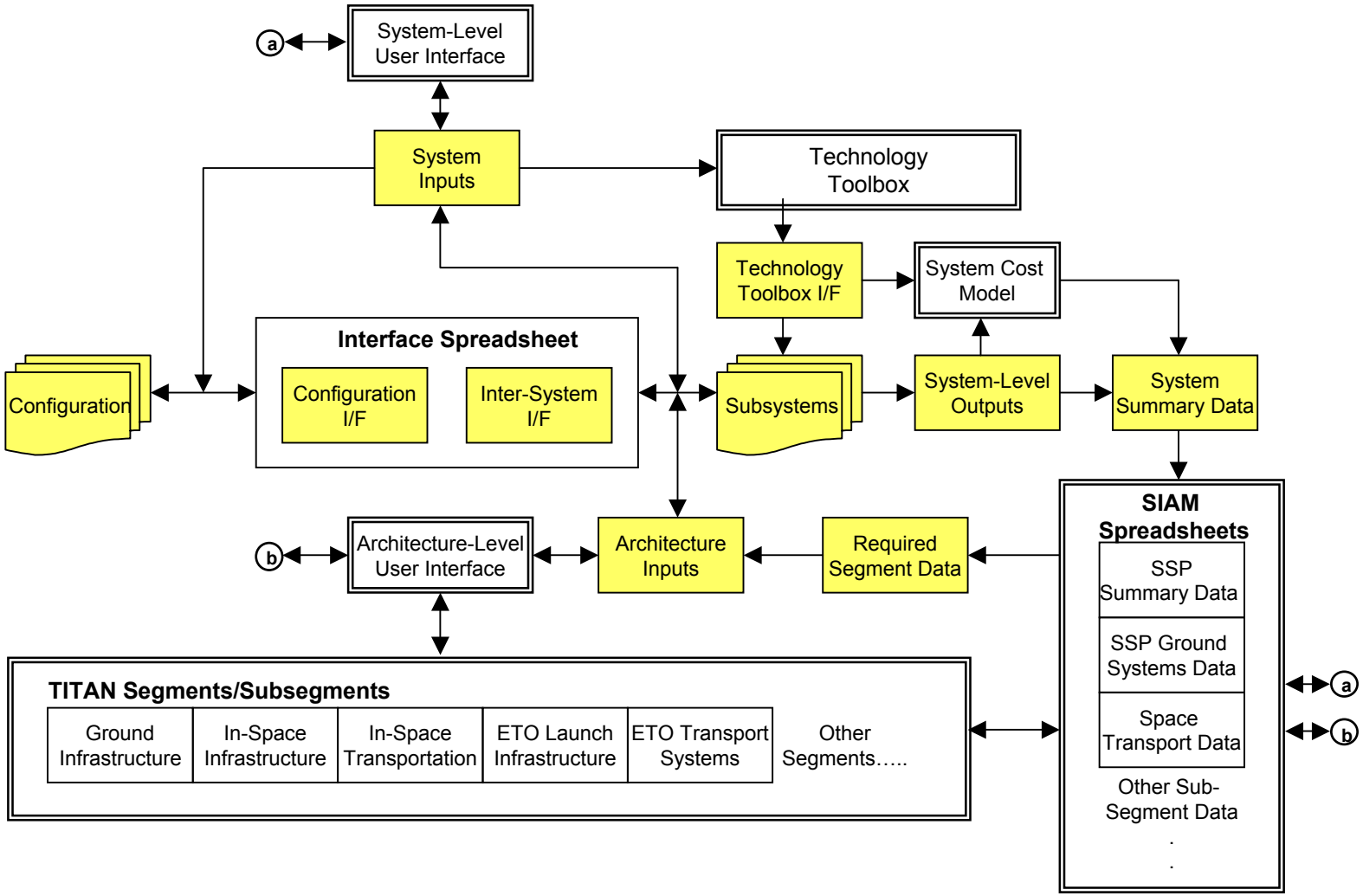
TITAN Model Architecture

TITAN Element Hierarchy - SSP Example

• **Capability Class**	Earth Neighborhood in Space
• **Mission**	Space Solar Power to Earth Markets
• **Architecture Segments**	In-Space Infrastructure
	ETO Transport Systems
	ETO Launch Infrastructure
	In-Space Transportation
	Non-Launch Ground Infrastructure
• **Subsegments/Systems**	SSP Satellite
	Reusable Launch Vehicle
	Spaceport Launch Facility
	SEP Propulsion Stage
	WPT Receiver
• **Subsystems**	SPG, WPT, STR, PMAD, ACS, PRP, etc.
• **Technologies**	SPG: SLA, TF, MBG, Rainbow, SD, etc.
	WPT: Magnetron, GaN, Klystron, Laser
	STR: Composite, Inflatable, Micro-Truss
	Other Subsys: Technologies in TTB

TITAN Model Architecture

Titan Sub-Segment Architecture, Spreadsheets & Information Flow

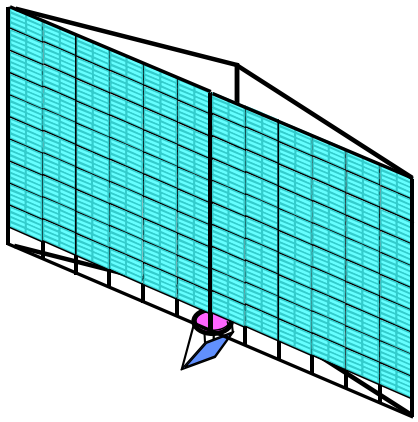


TITAN Model Architecture

Configuration Spreadsheet - Abacus Reflector Concept

List of Structural Elements & Dimensions (From System User Interface)

Solar Array Structure (Outer Dimensions)
Shape: (Rectangular, Circular, Elliptical, etc,)
Length:
Width:
Diameter:
Number:
Unit Arrays
Shape: (Rectangular, Circular, Elliptical, etc,)
Length:
Width:
Diameter:
Number
Reflector Structure (Backplane)
Length:
Width:
Number:
Reflectors
Shape: (Rectangular, Circular, Elliptical, etc,)
Length:
Width:
Diameter:
Number:
Transmitter Array Structure:
Diameter:
Depth:
Mast/Truss: #1 #2 #3 …...
Length
Number:
Payload Volume:
Length:
Width:
Depth:
Other Structures: Etc.



Scaling Inputs (From Configuration I/F)

Req. Solar Collection Area:
Cell Packing Factor:
Array Packing Factor:
Concentration Ratio:
Req. Transmitter Diameter:
Req. Payload Volume:
Others:

List of Structural Elements & Dimensions (Scaled Values based on Scaling Inputs)

Solar Array Structure (Outer Dimensions)
Shape: (Rectangular, Circular, Elliptical, etc,)
Length:
Width:
Diameter:
Number:
Unit Arrays
Shape: (Rectangular, Circular, Elliptical, etc,)
Length:
Width:
Diameter:
Number
Reflector Structure (Backplane)
Length:
Width:
Number:
Reflectors
Shape: (Rectangular, Circular, Elliptical, etc,)
Length:
Width:
Diameter:
Number:
Transmitter Array Structure:
Diameter:
Depth:
Mast/Truss: #1 #2 #3 …...
Length
Number:
Payload Volume:
Length:
Width:
Depth:
Other Structures: Etc.

TITAN Model Architecture

Configuration/Subsystem Interface Spreadsheet

Data Passed from Selected Configuration Spreadsheet

List of Structural Elements & Dimensions (Scaled Values based on Scaling Inputs)

Solar Array Structure (Outer Dimensions)
- Shape: (Rectangular, Circular, Elliptical, etc,)
- Length:
- Width:
- Diameter:
- Number:

Unit Arrays
- Shape: (Rectangular, Circular, Elliptical, etc,)
- Length:
- Width:
- Diameter:
- Number

Reflector Structure (Backplane)
- Length:
- Width:
- Number:

Reflectors
- Shape: (Rectangular, Circular, Elliptical, etc,)
- Length:
- Width:
- Diameter:
- Number:

Transmitter Array Structure:
- Diameter:
- Depth:

Mast/Truss: #1 #2 #3 …...
- Length
- Number:

Payload Volume:
- Length:
- Width:
- Depth:

Other Structures: Etc.

Solar Power Generation Shared Data

Wireless Power Trans Shared Data

PMAD&Cabling Shared Data

Thermal Control Shared Data

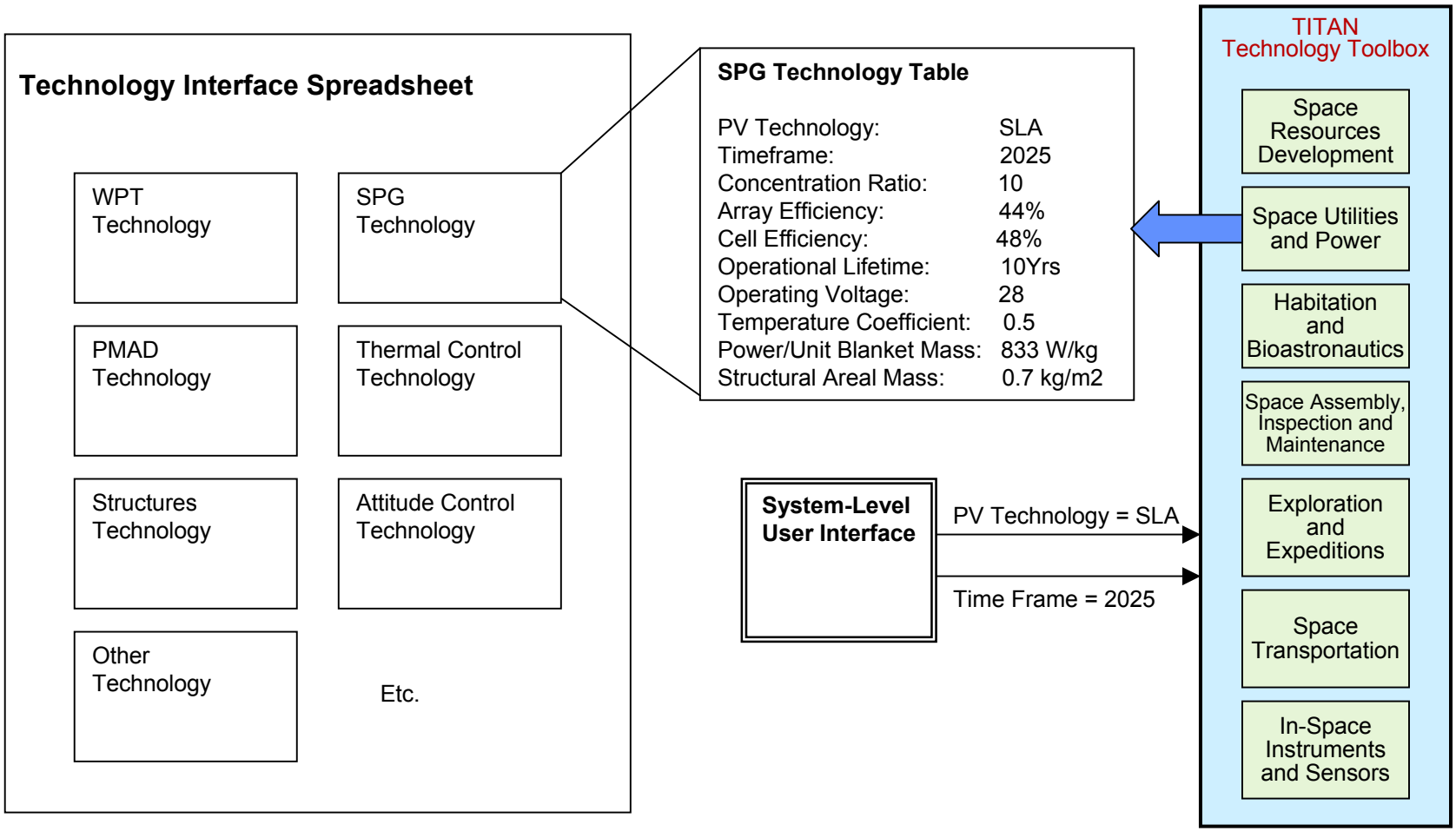
Attitude Control Shared Data

Structures Shared Data

Other Subsystem Shared Data

Data Passed by Subsystem Spreadsheets to be Shared with Other Subsystems

TITAN Model Architecture
Technology Interface Spreadsheet



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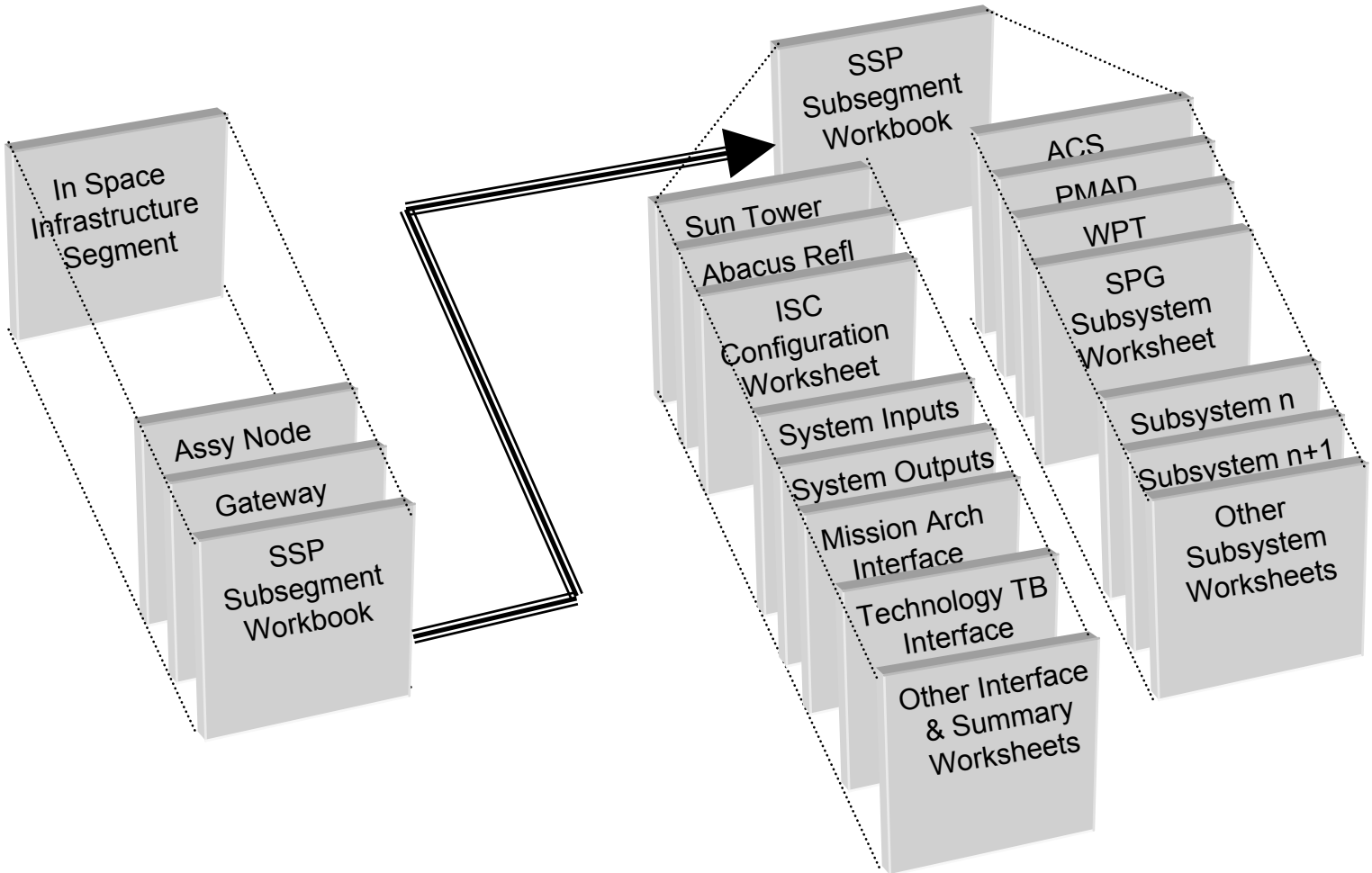
TITAN Model Architecture

TITAN Segment Decomposition (Example)



TITAN Model Architecture

Spreadsheets Required for Each Subsegment Workbook

- **Configuration:** One for each candidate concept/configuration
- **System Inputs:** Collects relevant system/subsystem inputs from user interface
- **Configuration/Subsystem I/F**: Used to connect configuration and subsystems
- **Subsystems:** One needed for each subsystem comprising configuration
- **Technology TB Interface:** Collects toolbox data for user-selected technologies
- **Architecture Inputs:** Collects mission architecture inputs from user interface
- **Segment Data:** Obtains data from other segments in architecture through SIAM
- **System Outputs:** Collects mass, performance, reliability data from subsystems
- **System Summary:** Adds cost, selected input & descriptive data to system output

AN APPROACH TO DEVELOPMENT AND INTEGRATION OF NEW TITAN MODEL SEGMENTS

Dr. Stephen J. Hoffman
Science Applications International Corporation
Houston, TX

Some Assumptions

- First assumption, there is a "standing" TITAN development team, responsible for building and maintaining the TITAN model
- Next, any new segment added to TITAN will come from one of two broad sources:
  - Studies initiated (and funded) by J. Mankins/Code M or the TITAN development team.
  - Models, spreadsheets, algorithms, and/or data generated from studies initiated by other programs or Codes (e.g., SLI, Code S advanced studies, etc.) that are adapted to fit the TITAN architecture
- In the first case it is assumed that the TITAN development team is intimately involved from the outset and any models developed will be compatible with TITAN.
- The second case will be the focus of the remainder of this package and will require a three-step process.

Process Phase 1, Initial Study

- During this phase, the study/assessment/modeling activity (external to TITAN) is conducted by a group of experts (aka the Study Team) using customized or specialized tools to carry out this task.
- At a minimum, this Study Team will generate data sufficient to answer their original charge. They may or may not develop models that are of use to TITAN; the data they generate will most likely cover only a portion of the trade space of interest to TITAN users. However, it is assumed that a determination has been made that the mission/vehicle will be a desirable additional segment within TITAN.

Process Phase 1 (page 2)

- One or more members of the TITAN development team will be assigned to work with the Study Team to provide guidance and/or support regarding compatibility requirements for any models that may eventually be used in TITAN. This support could be as little as a TITAN briefing plus occasional telephone contact up to full time participation in the Study Team tasks.
- The development team members will also review the products being developed to answer the original request and prepare a list of additional evaluations or data sets necessary for the TITAN model.

Process Phase 2, Transition

- During this phase the TITAN development team assumes the primary role with support from some or all of the Study Team members.
- Additional evaluations or trade studies to address data sets needed in TITAN are carried out by the Study Team (resources for this additional effort may be sought from the TITAN development team). To avoid the necessity of incorporating sophisticated models or analysis tools, some of these data may be provided to TITAN in the form of look-up tables or curve-fit formulas (e.g., the low thrust trajectory data contained in the Space Segment Model).
- The development team begins any necessary conversions to the Study Team models (with Study Team support) to make these models compatible with the TITAN environment.

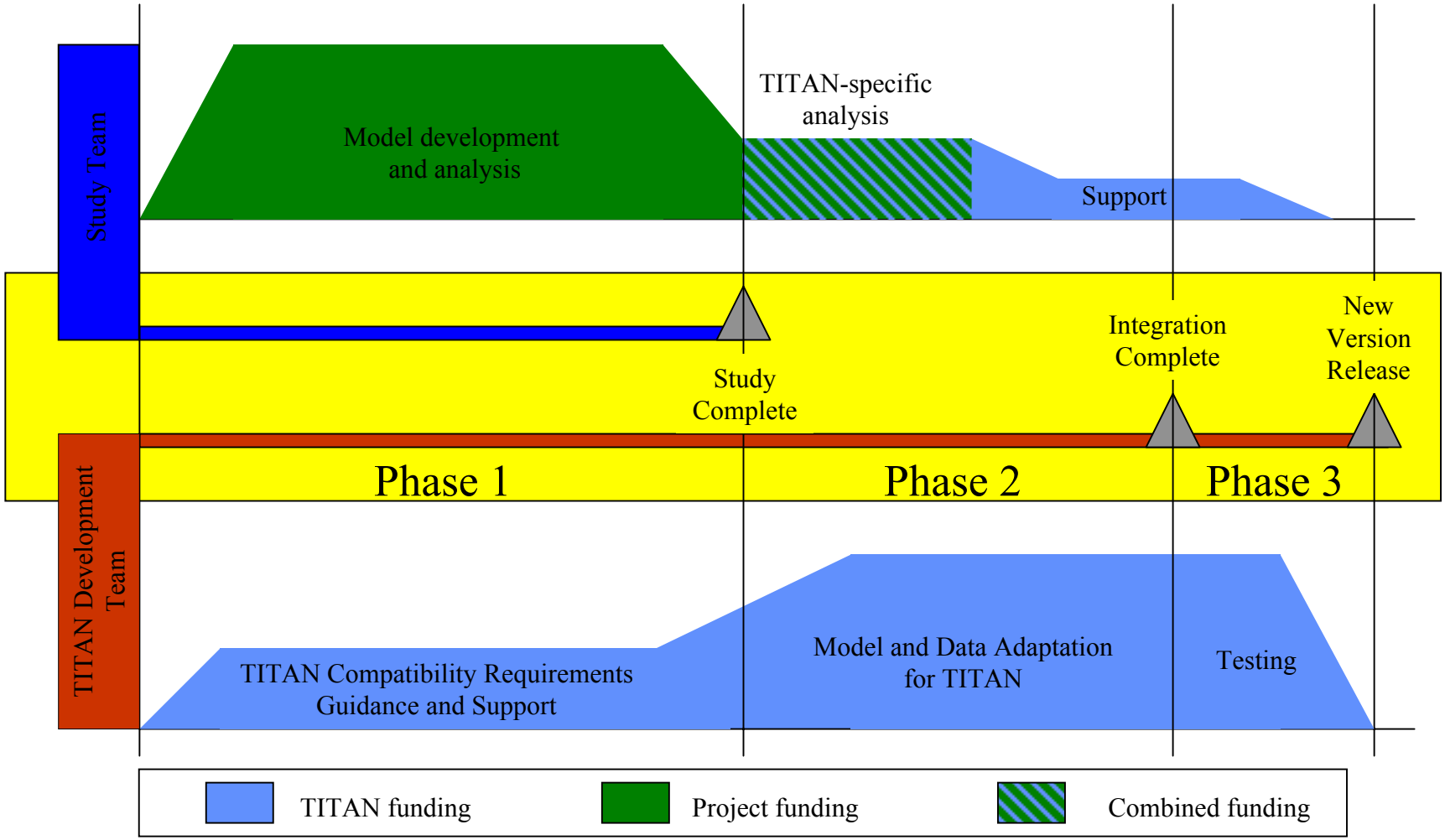
Process Phase 2 (page 2)

- The Study Team may also be asked to create additional model features for TITAN using their expertise (e.g., adding an RTG option to a segment model that was previously powered by solar arrays only). Resources for this additional effort may be sought from the TITAN development team. The development team incorporates these model features into the TITAN-compatible models.
- The TITAN development team continues working, with the support of the Study Team, to the point where all segment models and associated data sets are ready for testing within the TITAN environment.

Process Phase 3, Testing and Deployment

- The entire TITAN model is tested with new segment models and data sets in place and active.
- On satisfactory completion of these tests, the enhanced TITAN model is available for a new version release.

Relative LOE to Support TITAN Enhancements



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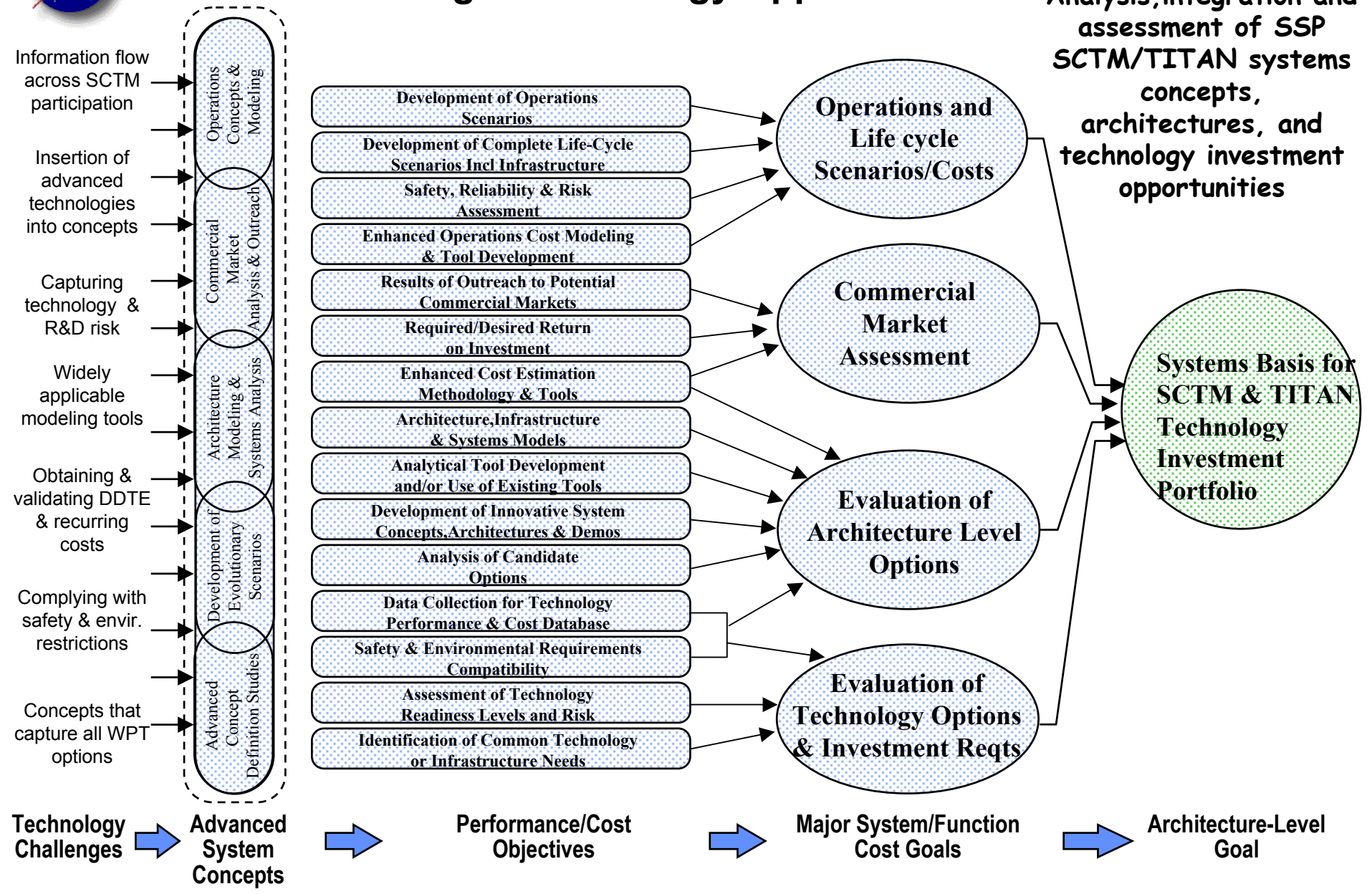
Implications

- The assumptions made and the process described has several implications on TITAN, including:
  - A dedicated, although probably not full time, development team
  - On-going funding for this team
  - A software development environment and standards that can be communicated to other study teams
  - Funding (potentially) for other study teams to conduct TITAN-specific trade studies, model development, or data generation piggybacked on to other non-TITAN studies

UPDATED (SLIGHTLY) SERT SIWG ROADMAPS

SCTM Systems Integration, Analysis and Modeling
Strategic Technology Approach

Strategic Goal:
Analysis, integration and assessment of SSP SCTM/TITAN systems concepts, architectures, and technology investment opportunities



SCTM Systems Integration, Analysis and Modeling
Space Solar Power Technology Investment Plan

DESCRIPTION

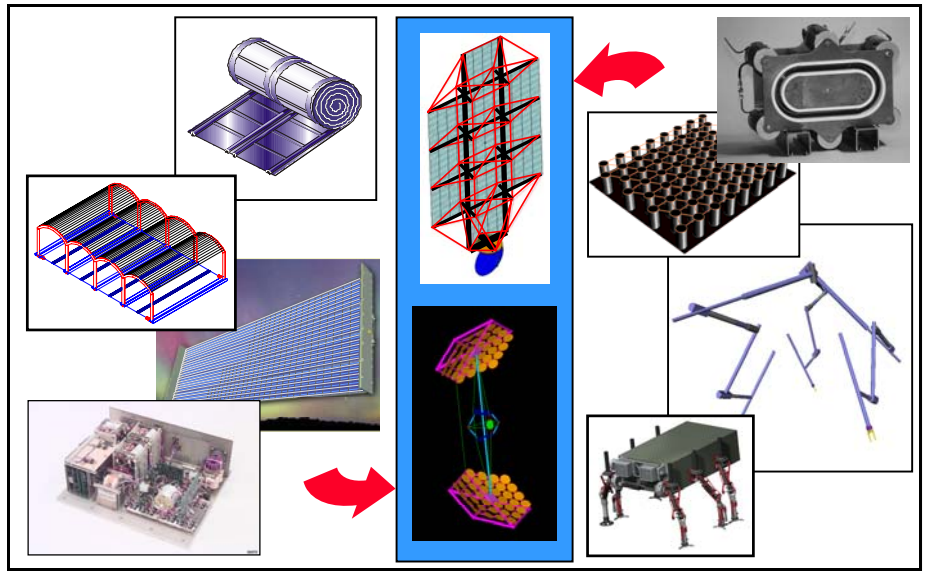
SSP Systems Integration includes developing and using detailed SSP system and subsystem models to identify promising SSP concepts,orbits & metrics to focus SSP R&D. Modeling will highlight interactions between subsystems and technologies that must be understood for system trades and to track the viability of concepts/design approaches as technologies mature.

APPROACH

Advanced concept definition studies
Development of evolutionary scenarios
Architecture modeling & systems analysis
Commercial market analysis & outreach
Operations concepts & modeling

PARTICIPANTS

NASA Glenn Research Center (Lead)
Other NASA centers: MSFC,JPL,JSC,GSFC
Non-NASA Organizations: SAIC,Futron,Boeing,Sverdrup,Aerospace,Alpha Technology
Universities: Auburn, Texas A&M, Georgia Tech



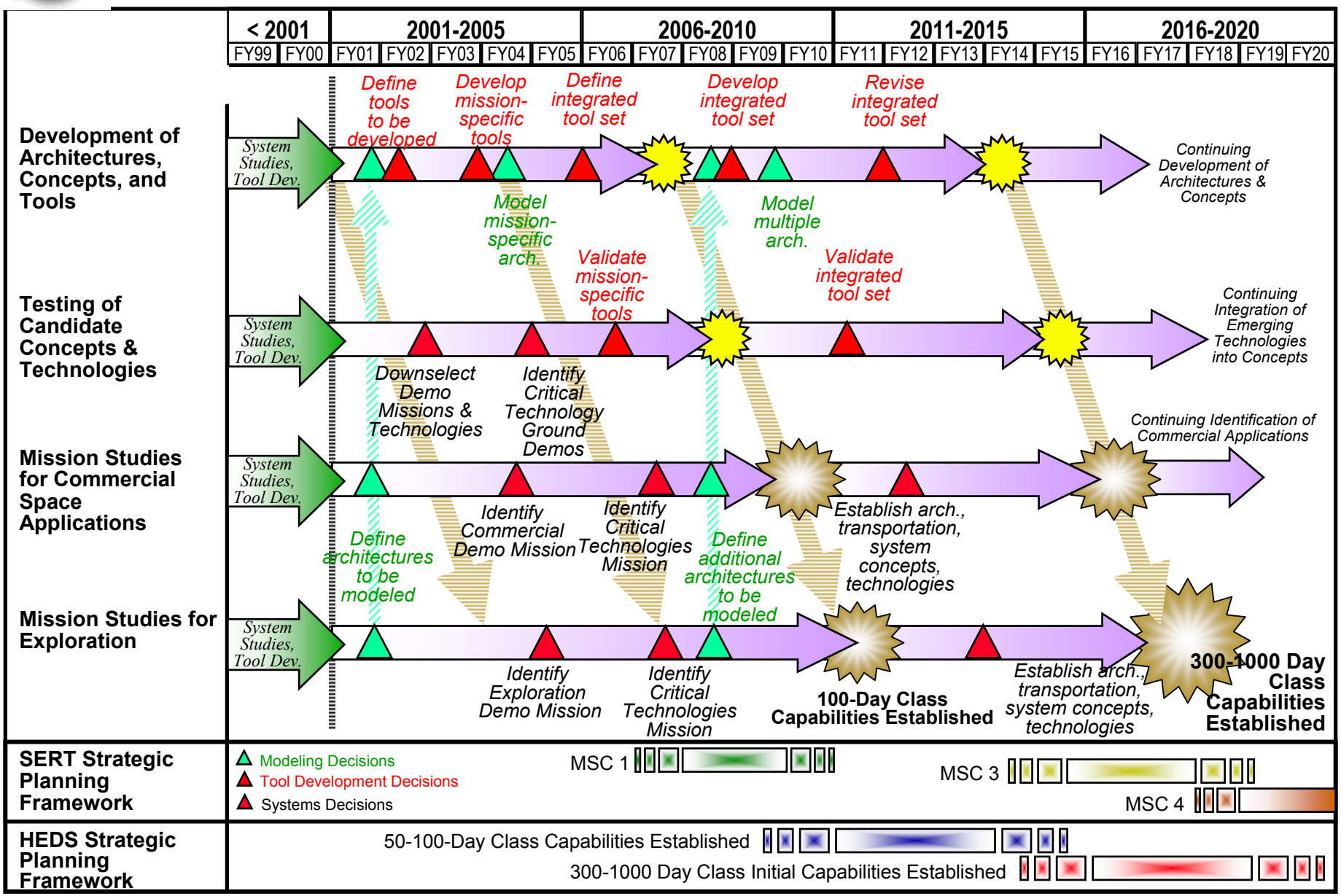
MAJOR MILESTONES

YEAR	ITEM
2001	Complete Databases,concept evaluation models/tools
2002	Identify candidate MSC1 concepts, missions & technologies
2003	Selection of MSC1 concept, technologies & mission objectives
2003	Identify risk mitigation demonstrations (if necessary)
2004	Definition of requirements for MSC1
2008	MSC1 launch

TECHNOLOGY ELEMENTS

- Enhanced information flow across full SCTM/TITAN participation
- Managing the insertion of advanced technologies into diverse system concepts
- Methodology for capturing R&D^3 or technology risk
- General purpose modeling tool linked to common technology database suitable for wide variety of configurations & applications
- Methodology for ascertaining/validating DDT&E & recurring cost estimates for new technologies or technology advancements
- Impact of complying with safety & environmental restrictions
- System concept models that capture microwave, laser & other viable WPT approaches
- Design and analysis tools including databases, technologies, & mission unique elements

SCTM Systems Integration, Analysis and Modeling
Strategic R&T Schedule/Milestone Road Map



SIWG Near-Term Plans

- **Modeling Activities**
  - Update SSM Subsystem Worksheets as Needed
  - Model Boeing/Aerospace Laser Configurations
  - Complete Conversion of SSM to New (TITAN) Modeling Architecture
  - Enable Use of THREADS Technology Database in Models
  - Identify a Preferred Cost Estimation Approach for Model.
  - Model and Evaluate Selected New Concepts (e.g. HotDot, Solar-Pumped Laser Concepts, etc.)
  - Work with SCTM Program Management to Address NRC Recommendation for Model Peer Review

- **Systems Integration Activities**
  - Resume Regularly Scheduled (Monthly) SIWG Telecon
  - Contribute Information to other SSP Telecons, e.g., WPT, TFD
  - Disseminate Systems and Analysis Information to R&TWG's
  - Obtain Technology Information as Needed from R&TWG's
  - Participate in Concept Development and Selection Activities